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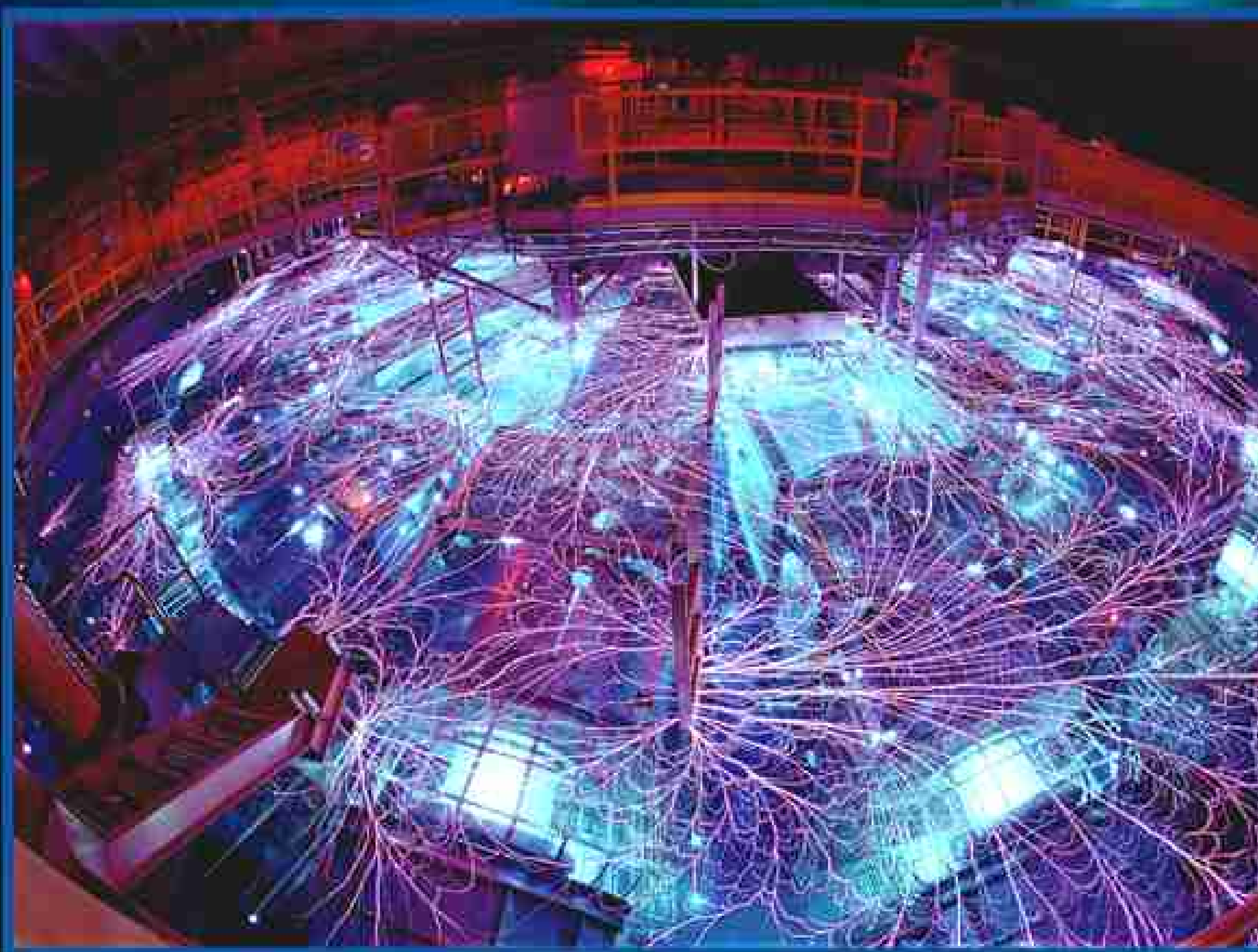

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BUILDING A BETTER MICROSYSTEM

Five-Level Process Could Become Industry Standard

This image shows a ratcheting system fabricated in the five-level technology. Twenty of these gears fit on a period in a newspaper sentence.

A new, advanced, five-level polysilicon surface micromachining process pioneered at Sandia National Laboratories promises that microelectromechanical systems (MEMS) of the future will be more reliable and capable of doing increasingly complex tasks.

"This five-level polysilicon surface micromachining technology has the potential of becoming the industry standard, replacing the more commonly used two- or three-level polysilicon surface micromachining approaches," said Sandia engineer Steve Rodgers, who with colleague Jeff Sniegowski has spent the past several years prototyping designs and developing the innovative process. "We have been working hard to baseline the technology as a reproducible manufacturing process, and we're getting there." The new technology was developed at Sandia's Microelectronics Development Laboratory. MEMS devices made from the five-level process eventually will be manufactured in the new Microsystems and Engineering Sciences Application (MESA) facility being planned for construction at Sandia.

MEMS, complex machines with micron-size features, can be found in a variety of products, including optical devices, computer-game joy sticks, car-airbag sensors, ink-jet printers, projection displays, and more. They are so small that they are almost imperceptible to the human eye and have moving parts no bigger than a red blood cell.

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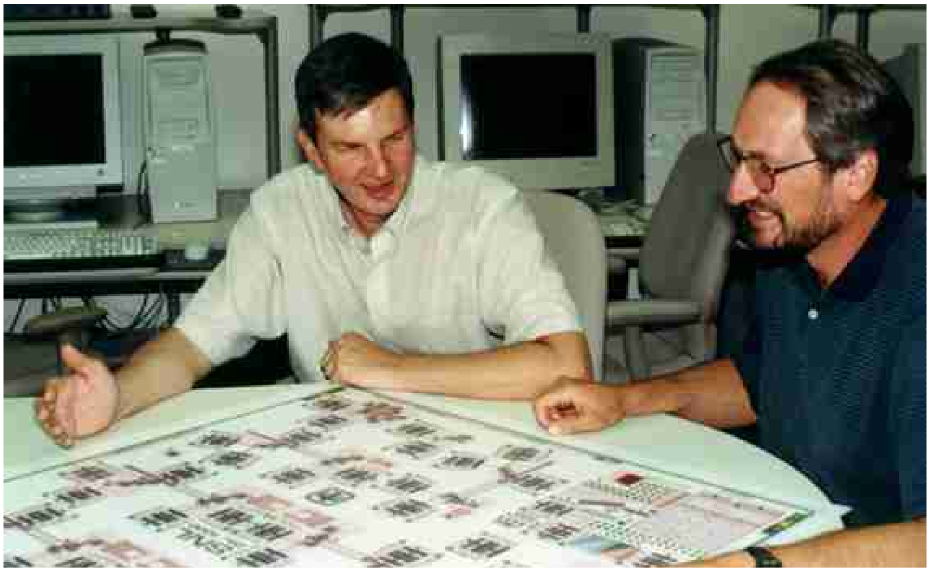
Sandia will begin offering the five-level technology next spring to external customers for prototyping purposes. Information about all MEMS courses is available on Sandia's micromachine Web page located at *http://www.mdl.sandia.gov/micromachine.*

Almost all of today's surface micromachine components are designed for and fabricated in technologies that incorporate three or fewer levels of structural materials. The levels are typically deposited as thin films of polysilicon that are about one to two microns thick. These films are separated by air gaps that initially are defined



Sandia's Steve Rodgers (left) and Jeff Sniegowski look over a computer schematic of a five-level polysilicon surface micromachine.

by layers of sacrificial silicon dioxide (sacrificial because they will eventually be eliminated) of about the same thickness. Processes with thicker polysilicon film — up to tens of microns — exist, but are typically limited to only that layer.

"In general, the more layers of structural material that a designer has to work with, the more complicated the device that can be fabricated," said Sniegowski, who developed the fabrication technology for the five-level layering method. "Therefore, surface micromachined components have greater functionality than bulk micromachined parts."

That's why, he added, the five-level polysilicon surface micromachine process that incorporates four layers of structural films, plus an electrical interconnect layer, is so attractive.

"This technology permits mechanical functionality that only a five- or more layer process could offer," Sniegowski said. "It provides a base for designing truly sophisticated multilevel microelectromechanical systems, while simultaneously offering much of the yield and robustness that typically is associated with single-level micromachining technology."

A two-level polysilicon process has only one layer of structural material, with the other level defining the ground plane. Such a technology is useful for fabricating simple sensors and

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actuators. With three levels, it is possible to create gears with hubs, while the four-level technology provides an additional layer of material that can be used to define linkage arms that move above the plane of the gears, enabling a continuous 360-degree rotation. The five-level technology expands on this to permit complex interacting mechanisms to be fabricated on moving platforms.

But to do this, several challenges had to be overcome, which Sniegowski and Rodgers have met. For example, as additional layers are added, more texture appears on the surface. This occurs because the top layer acquires the characteristics of all the lower layers, including high and low spots. The result is the creation of protrusions, called mechanical parasitics, that extend from the upper mechanical layer to lower areas. They can interfere with operation.

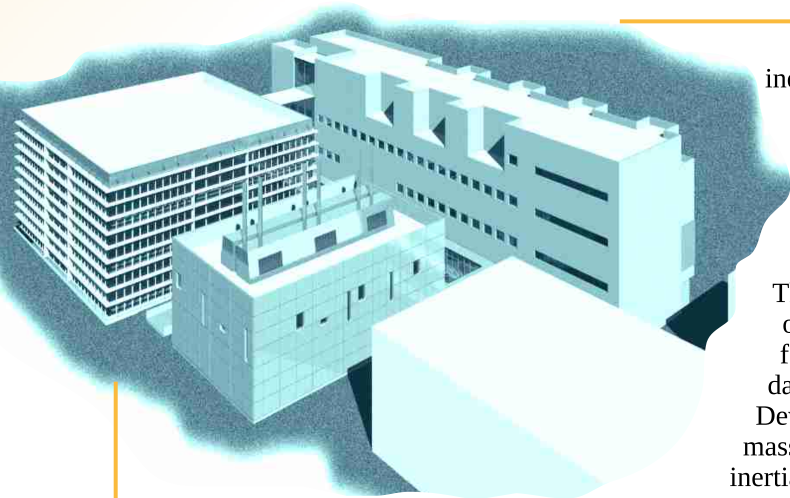
These parasitics, Sniegowski said, can significantly "constrain the design." If the design doesn't take them into account, they could easily "collide with the teeth and prevent rotation of the gear."

To eliminate this problem, a Sandia team led by process engineer Dale Hetherington modified and patented a process commonly used in manufacturing integrated circuits — chemical mechanical polishing — to planarize (flatten) the surface. High spots are eliminated after a very thick layer of sacrificial oxide covers all previous layers. Through chemical mechanical polishing, the high spots are eroded, producing a uniform flat surface.

Rodgers said the new five-layer process provides a foundation for fabricating components that offer high performance, reliability, and robustness. However, work continues to improve the process even further. "We are now adding the final touches before offering it for widespread use," he said.

Technical contacts:
Steve Rodgers,
(505) 844-1784
rodgersm@sandia.gov

Jeff Sniegowski,
(505) 844-2718
sniegojj@sandia.gov



Planned MESA Facility Gets DOE Nod

The Department of Energy has given Sandia National Laboratories the go-ahead to develop a conceptual design for a $300 million Microsystems and Engineering Sciences Application (MESA) facility. The purpose of the project is to join Sandia's expertise in weapons design, very fast computing, and microsystems into an immersive environment in which scientists can imagine, design, and create the 21st century's best non-nuclear components for nuclear weapons.

Other benefits include offering American businesses and universities new opportunities to advance through use of the cutting-edge science that the facility and its programs will provide in microsystems and computer-aided design and simulations.

One military advantage of the new microsystems will be that they are expected to reduce the likelihood of malfunction in the event of an unexpected event, like a crash involving nuclear weapons.

"A big arming or safety device involved in an accident severe enough to destroy or fire off a missile would most likely be damaged as much as the explosive device," said David Plummer, nuclear weapons representative for MESA.

Microsystems designed by high-speed computers are smaller than postage stamps. Their components have little mass, so they have little inertia — the force that keeps an object moving once it is put in motion. Inertia throws passengers forward, for example, when a car comes to a sudden stop. The amount of inertia an object possesses is a key factor in how much damage it may suffer. Devices of extremely low mass, having almost no inertia, have no problem stopping very suddenly and thus are difficult to destroy impact.

"As the magnitudes of potential accidents increase — as jet fuel gets hotter, as air speeds get faster — so do the possibilities of accidents exceeding our current controls. We need more rugged safety devices," said Plummer. "MESA will produce them."

The primary function of the facility will be the defense of the United States, said Tom Hunter, senior vice-president of nuclear weapons. The facility also will include weapon component modeling and simulation, weapon certification, and embedded microsystems.

However, MESA also represents the leading edge of industry's interest in intelligent microsystems, said Dan Hartley, vice president for laboratory development. "The demand for less expensive, more intelligent, smaller systems is ubiquitous in industry, and we believe that what we're doing here represents the birth of a new field of business endeavor."

Al Romig, Sandia vice president for science, technology, and components, said, "This will create a capability to do our business in a new way. It'll revolutionize the way we'll refurbish the nuclear stockpile and build new space satellites. It also will be an opportunity to drive the creation of entirely new industries in the United States, using our Science and Technology Park."

"Conceptually, MESA is a new way of designing intelligent, autonomous, reliable microsystems from the outset and will be the wave of the future for all complex commercial products that will incorporate microsystems, such as cars, planes, and computers," said David Goldheim, director for Sandia's corporate business development and partnerships. "At an appropriate time, we plan to ask businesses to become involved in the design of portions of the program. Industry will help design and use parts of the new facility."

MESA is also of interest to universities "because in our meetings with deans, microsystems are a high priority with them as well, and they want to have more to do with us because we will be defining the leading edge," added Hartley.

Regarding students, Don Cook, director of the MESA project said, "Students in school are being trained in new technologies. We can't expect to train the brightest graduates on old technology. We want them to advance new technology even further. That's why we're a national lab."

Approximately $95 million is slated to be funneled into new equipment for MESA, said Cook.

Said John Stichman, director of weapons systems engineering in New Mexico for Sandia, "As we refurbish weapons, we need to know that those weapons we return to the stockpile meet our safety and capability requirements. These requirements pertain to the next several decades of life these weapons would have in the stockpile. Microsystems hold the promise to provide the most capable implementation of the safety of refurbished weapons. The nuclear weapon systems organization is working closely with the MESA planning staff to assure that MESA is well-aligned with weapons systems design and development."

The tentative schedule is to begin engineering design in fiscal year 2000 and construction in 2001. The project is scheduled for completion by 2003, and to be fully operational by 2004. MESA eventually will house 600 employees.

Technical contact:
Don Cook
(505) 845-7446
dlcook@sandia.gov

If there is a "secret of success" for Sandia's past 50 years, it is this coming-together of world-class experts from a variety of training and experience to merge their unique contributions in technically challenging endeavors.

C. Paul Robinson
President and Laboratories Director
Sandia National Laboratories

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Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0129